Claims

1. An automated method for frequency compensated communications reception characterised in that it includes compensating for frequency offset in a received signal by adaptively forming a combination of basis functions and a training sequence that collectively approximate to a desired frequency-shifted signal to be acquired.

2. A method according to Claim 1 characterised in that it includes constructing a reference signal or comparison training sequence that is an adaptively formed combination of basis functions and the training sequence.

3. A method according to Claim 2 for acquiring a signal with a receiver having multiple antenna elements, characterised in that the method includes constructing the reference signal by minimising a cost function constructed from an adaptively weighted combination of basis functions, a training sequence and a received signal, together with a constraint to obtain non-trivial solutions.

4. A method according to Claim 3 characterised in that the constraint requires non-zero signal power.

5. A method according to Claim 3 characterised in that the cost function is J given by: $J = \|\mathbf{Xw} - \mathbf{CFv}\|^2 + \lambda\left(\mathbf{w}^H\mathbf{X}^H\mathbf{Xw} - 1\right)$, where $\mathbf{X}$ is a matrix of received signal samples, $\mathbf{w}$ is a vector of beamforming weights which are adaptive to minimise J, $\mathbf{C}$ is a diagonal matrix having elements of the training sequence on its diagonal, $\mathbf{F}$ is a matrix having columns defining respective basis functions, $\mathbf{v}$ is a vector of weights which are adaptive to minimise J, superscript index H indicates a complex conjugate transpose and λ is a Lagrange multiplier and the term which incorporates it is to constrain beamformer output power to be non-zero.

6. A method according to Claim 5 characterised in that it includes determining the adaptive weight vectors $\mathbf{w}$ and $\mathbf{v}$ at intervals from true estimates of a correlation matrix determined from multiple data vectors and from inverses of such estimates recursively updated to reflect successive new data vectors which are rows of the matrix $\mathbf{X}$.

7. A method according to Claim 6 characterised in that it includes recursively updating inverse correlation matrices by:

a) forming a vector $\mathbf{u}(\mathrm{n})$ having a first element $\mathrm{u}_1(\mathrm{n})$ equal to $\sqrt{\mathrm{U}_{1,1}(\mathrm{n})}$ and other elements $\mathrm{u}_\mathrm{p}(\mathrm{n})$ (p= 2 to M) which are respective ratios $\mathbf{U}_{\mathrm{p},1}(\mathrm{n})/\mathrm{u}_1(\mathrm{n})$, $\mathbf{U}_{\mathrm{p},1}(\mathrm{n})$ is a pth element of a first column of a matrix $\mathbf{U}(\mathrm{n})$, the matrix $\mathbf{U}(\mathrm{n}) \equiv \mathbf{u}(\mathrm{n})\mathbf{u}^H(\mathrm{n}) = \mathbf{x}(\mathrm{n})\mathbf{x}^H(\mathrm{n}) - \mathbf{x}(\mathrm{n}-\mathrm{K}+1)\mathbf{x}^H(\mathrm{n}-\mathrm{K}+1)$, $\mathbf{x}(\mathrm{n})$ is a most recent data vector and $\mathbf{x}(\mathrm{n}-\mathrm{K}+1)$ is a least recent data vector involved in updating and $\mathbf{x}(\mathrm{n})\mathbf{x}^H(\mathrm{n})$ and $\mathbf{x}(\mathrm{n}-\mathrm{K}+1)\mathbf{x}^H(\mathrm{n}-\mathrm{K}+1)$ are correlation matrices;

b) premultiplying a previous inverse correlation matrix $\mathbf{P}(\mathrm{n}-1)$ by vector $\mathbf{u}^H(\mathrm{n})$ and postmultiplied by vector $\mathbf{u}(\mathrm{n})$ to form a product and adding the product to a forget factor to form a sum;

c) postmultiplying the previous inverse correlation matrix $\mathbf{P}(\mathrm{n}-1)$ by vector $\mathbf{u}(n)$ and dividing by the said sum to form a quotient; and

d) subtracting the quotient from the previous inverse correlation matrix $\mathbf{P}(\mathrm{n}-1)$ to provide a difference.

8. A method according to Claim 2 for acquiring a signal with a receiver having a single antenna element, characterised in that the method includes constructing the reference signal by minimising a cost function constructed from an adaptively weighted combination of basis functions, a scaled received signal and a constraint requiring non-zero signal power.

9. A method according to Claim 8 characterised in that the cost function is J given by: $J = \|\mathbf{x} - \mathbf{CFv}\|^2$, where $\mathbf{x}$ is a vector of received signal samples, and $\mathbf{v}$, $\mathbf{C}$ and $\mathbf{F}$ are as defined earlier.

10. A method according to Claim 8 characterised in that the cost function is J given by: $J = \|\alpha\mathbf{x} - \mathbf{Gv}\|^2 + \lambda\left(\alpha^*\mathbf{x}^H\mathbf{x}\alpha - 1\right)$, where α is a scaling factor, $\mathbf{x}$ is a vector of received signal samples, $\mathbf{G}$ is a matrix equal to $\mathbf{CF}$ and $\mathbf{v}$, λ, $\mathbf{C}$, $\mathbf{F}$ and H are

as defined earlier.

11. Apparatus for frequency compensated communications reception characterised in that it includes means for compensating for frequency offset in a received signal by adaptively forming a combination of basis functions and a training sequence that collectively approximate to a desired frequency-shifted signal to be acquired.

12. Apparatus according to Claim 11 characterised in that it includes means for constructing a reference signal or comparison training sequence that is an adaptively formed combination of basis functions and the training sequence.

13. Apparatus according to Claim 12 having a receiver with multiple antenna elements for acquiring the received signal, characterised in that the apparatus includes means for constructing the reference signal by minimising a cost function constructed from an adaptively weighted combination of basis functions, a training sequence and a received signal, together with a constraint to obtain non-trivial solutions.

14. Apparatus according to Claim 13 characterised in that the constraint requires non-zero signal power.

15. Apparatus according to Claim 13 characterised in that the cost function is J given by: $J = \|\mathbf{Xw} - \mathbf{CFv}\|^2 + \lambda\left(\mathbf{w}^H \mathbf{X}^H \mathbf{Xw} - 1\right)$, where $\mathbf{X}$ is a matrix of received signal samples, $\mathbf{w}$ is a vector of beamforming weights which are adaptive to minimise J, $\mathbf{C}$ is a diagonal matrix having elements of the training sequence on its diagonal, $\mathbf{F}$ is a matrix having columns defining respective basis functions, $\mathbf{v}$ is a vector of weights which are adaptive to minimise J, superscript index H indicates a complex conjugate transpose and λ is a Lagrange multiplier and the term which incorporates it is to constrain beamformer output power to be non-zero.

16. Apparatus according to Claim 15 characterised in that it includes means for determining the adaptive weight vectors $\mathbf{w}$ and $\mathbf{v}$ at intervals from true estimates of a correlation matrix determined from multiple data vectors and from inverses of such estimates recursively updated to reflect successive new data vectors which are rows of the matrix $\mathbf{X}$.

17. Apparatus according to Claim 16 characterised in that it includes means for recursively updating inverse correlation matrices by:

    a) forming a vector $\mathbf{u}(\mathrm{n})$ having a first element $\mathrm{u}_1(\mathrm{n})$ equal to $\sqrt{\mathrm{U}_{1,1}(\mathrm{n})}$ and other elements $\mathrm{u}_\mathrm{p}(\mathrm{n})$ (p= 2 to M) which are respective ratios $\mathbf{U}_{\mathrm{p},1}(\mathrm{n})/\mathrm{u}_1(\mathrm{n})$, $\mathbf{U}_{\mathrm{p},1}(\mathrm{n})$is a pth element of a first column of a matrix $\mathbf{U}(\mathrm{n})$, the matrix $\mathbf{U}(\mathrm{n}) \equiv \mathbf{u}(\mathrm{n})\mathbf{u}^H(\mathrm{n}) = \mathbf{x}(\mathrm{n})\mathbf{x}^H(\mathrm{n}) - \mathbf{x}(\mathrm{n}-\mathrm{K}+1)\mathbf{x}^H(\mathrm{n}-\mathrm{K}+1)$, $\mathbf{x}(\mathrm{n})$ is a most recent data vector and $\mathbf{x}(\mathrm{n}-\mathrm{K}+1)$ is a least recent data vector involved in updating and $\mathbf{x}(\mathrm{n})\mathbf{x}^H(\mathrm{n})$ and $\mathbf{x}(\mathrm{n}-\mathrm{K}+1)\mathbf{x}^H(\mathrm{n}-\mathrm{K}+1)$ are correlation matrices;

    b) premultiplying a previous inverse correlation matrix $\mathbf{P}(\mathrm{n}-1)$ by vector $\mathbf{u}^H(\mathrm{n})$ and postmultiplied by vector $\mathbf{u}(\mathrm{n})$ to form a product and adding the product to a forget factor to form a sum;

    c) postmultiplying the previous inverse correlation matrix $\mathbf{P}(\mathrm{n}-1)$ by vector $\mathbf{u}(\mathrm{n})$ and dividing by the said sum to form a quotient; and

    d) subtracting the quotient from the previous inverse correlation matrix $\mathbf{P}(\mathrm{n}-1)$ to provide a difference.

18. Apparatus according to Claim 12 having a receiver with a single antenna element for acquiring the received signal, characterised in that the apparatus includes means for constructing the reference signal by minimising a cost function constructed from an adaptively weighted combination of basis functions, a scaled received signal and a constraint requiring non-zero signal power.

19. Apparatus according to Claim 18 characterised in that the cost function is J given by: $J = \|\mathbf{x} - \mathbf{CFv}\|^2$, where $\mathbf{x}$ is a vector of received signal samples, and $\mathbf{v}$, $\mathbf{C}$ and $\mathbf{F}$ are as defined earlier.

20. Apparatus according to Claim 18 characterised in that the cost function is J given by: $J = \|\alpha\mathbf{x} - \mathbf{Gv}\|^2 + \lambda\left(\alpha^*\mathbf{x}^H\mathbf{x}\alpha - 1\right)$, where α is a scaling factor, $\mathbf{x}$ is a vector of received signal samples, $\mathbf{G}$ is a matrix equal to $\mathbf{CF}$ and $\mathbf{v}$, λ, $\mathbf{C}$, $\mathbf{F}$ and H are

as defined earlier.

21. Computer software for controlling a computer processor and for use in frequency compensated communications reception characterised in that it includes program code instructions for compensating for frequency offset in a received signal by adaptively forming a combination of basis functions and a training sequence that collectively approximate to a desired frequency-shifted signal to be acquired.

22. Computer software according to Claim 21 characterised in that it includes program code instructions for constructing a reference signal or comparison training sequence that is an adaptively formed combination of basis functions and the training sequence.

23. Computer software according to Claim 22 for use in processing received signals acquired by a receiver with multiple antenna elements, characterised in that the computer software includes program code instructions for constructing the reference signal by minimising a cost function constructed from an adaptively weighted combination of basis functions, a training sequence and a received signal, together with a constraint to obtain non-trivial solutions.

24. Computer software according to Claim 23 characterised in that the constraint requires non-zero signal power.

25. Computer software according to Claim 23 characterised in that the cost function is J given by: $J = \|\mathbf{Xw} - \mathbf{CFv}\|^2 + \lambda\left(\mathbf{w}^H \mathbf{X}^H \mathbf{Xw} - 1\right)$, where $\mathbf{X}$ is a matrix of received signal samples, $\mathbf{w}$ is a vector of beamforming weights which are adaptive to minimise J, $\mathbf{C}$ is a diagonal matrix having elements of the training sequence on its diagonal, $\mathbf{F}$ is a matrix having columns defining respective basis functions, $\mathbf{v}$ is a vector of weights which are adaptive to minimise J, superscript index H indicates a complex conjugate transpose and λ is a Lagrange multiplier and the term which incorporates it is to constrain beamformer output power to be non-zero.

26. Computer software according to Claim 25 characterised in that it includes program code instructions for determining the adaptive weight vectors $\mathbf{w}$ and $\mathbf{v}$ at intervals from true estimates of a correlation matrix determined from multiple data vectors

and from inverses of such estimates recursively updated to reflect successive new data vectors which are rows of the matrix $\mathbf{X}$.

27. Computer software according to Claim 26 characterised in that it includes program code instructions for recursively updating inverse correlation matrices by:

a) forming a vector $\mathbf{u}(n)$ having a first element $u_1(n)$ equal to $\sqrt{U_{1,1}(n)}$ and other elements $u_p(n)$ (p= 2 to M) which are respective ratios $\mathbf{U}_{p,1}(n)/u_1(n)$, $\mathbf{U}_{p,1}(n)$ is a pth element of a first column of a matrix $\mathbf{U}(n)$, the matrix $\mathbf{U}(n) \equiv \mathbf{u}(n)\mathbf{u}^H(n) = \mathbf{x}(n)\mathbf{x}^H(n) - \mathbf{x}(n-K+1)\mathbf{x}^H(n-K+1)$, $\mathbf{x}(n)$ is a most recent data vector and $\mathbf{x}(n-K+1)$ is a least recent data vector involved in updating and $\mathbf{x}(n)\mathbf{x}^H(n)$ and $\mathbf{x}(n-K+1)\mathbf{x}^H(n-K+1)$ are correlation matrices;

b) premultiplying a previous inverse correlation matrix $\mathbf{P}(n-1)$ by vector $\mathbf{u}^H(n)$ and postmultiplied by vector $\mathbf{u}(n)$ to form a product and adding the product to a forget factor to form a sum;

c) postmultiplying the previous inverse correlation matrix $\mathbf{P}(n-1)$ by vector $\mathbf{u}(n)$ and dividing by the said sum to form a quotient; and

d) subtracting the quotient from the previous inverse correlation matrix $\mathbf{P}(n-1)$ to provide a difference.

28. Computer software according to Claim 22 for use in processing received signals acquired by a receiver with a single antenna element, characterised in that the computer software includes program code instructions for constructing the reference signal by minimising a cost function constructed from an adaptively weighted combination of basis functions, a scaled received signal and a constraint requiring non-zero signal power.

29. Computer software according to Claim 28 characterised in that the cost function is J given by: $J = \|\mathbf{x} - \mathbf{CFv}\|^2$, where $\mathbf{x}$ is a vector of received signal samples, and $\mathbf{v}$, $\mathbf{C}$ and $\mathbf{F}$ are as defined earlier.

30. Computer software according to Claim 28 characterised in that the cost function is J given by: $J = \|\alpha\mathbf{x} - \mathbf{Gv}\|^2 + \lambda\left(\alpha^*\mathbf{x}^H\mathbf{x}\alpha - 1\right)$, where α is a scaling factor, $\mathbf{x}$ is a vector of received signal samples, $\mathbf{G}$ is a matrix equal to $\mathbf{CF}$ and $\mathbf{v}$, λ, $\mathbf{C}$, $\mathbf{F}$ and H are as defined earlier.